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A Surrogate Model for the Operation Cost of City to City Commuter Airline Service for Sustainable Regional Aviation

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Abstract

In this study a surrogate model based Operation Cost and Feasibility (OCF) analysis is introduced for the regional commuter airline operation economics. For an integrated economic, social and cultural sustainable development, direct city to city air travel has been accepted as an important fast and flexible mode of transportation. On the other hand, route networks of existing airlines are mostly constructed between major hubs and hub spoke cities and airlines usually pick profitable routes and cancel money-losing ones. In present study operational economics of city to city air travel with commuter aircraft is studied with a reversed approach; the least number of passengers for possible lowest cost per passenger is considered rather than a conventional break-even Load Factor for pre-selected aircraft for a network routes. In other words, costs of travel for per passenger on each selected route are calculated instead of break-even number of passenger. On Overall Evaluation Criteria for Costs (OEC_C) is defined for a collective-cumulative cost per passenger for a given network as the function of the output variables of the airline operational cost analysis. As the next step Design of Experiments (DoE) is constructed for the input cost variables with their maximum and minimum values. One output of this DoE analysis is the Pareto Chart which ranks the input variables in terms of their effect on the defined OEC_C. Response Surface for the OEC_C is the Surrogate Model (SM) of the operational cost. Several examples for different OEC_C and their corresponding SMs, which represent different cost versus profit dynamics, are presented.

Keywords: airline operation cost, design of experiments, response surface

1. INTRODUCTION

Few inventions have changed how people live and experience the world as much as the invention of the airplane. During both World Wars, government subsidies and demands for new airplanes vastly improved techniques for their design and construction. Following the World War II, the first commercial airplane routes were set up in Europe. Over time, air travel has become so commonplace that it would be hard to imagine life without it. The airline industry, therefore, certainly has progressed. It has also altered the way in which people live and conduct business by shortening travel time and altering our concept of distance, making it possible for us to visit and conduct business in places once considered remote. The airline industry exists in an intensely competitive market. In recent years, there has been an industry-wide shakedown, which will have far-reaching effects on the industry's trend towards expanding domestic and international services. In the past, the airline industry was at least partly government owned. The airline industry can be separated into four categories by the U.S. Department of Transportation (DOT):

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- **International** - 130+ seat planes that have the ability to take passengers just about anywhere in the world. Companies in this category typically have annual revenue of $1 billion or more.
- **National** - Usually these airlines seat 100-150 people and have revenues between $100 million and $1 billion.
- **Regional** - Companies with revenues less than $100 million that focus on short-haul flights.
- **Cargo** - These are airlines generally transport goods.

Airport capacity, route structures, technology and costs to lease or buy the physical aircraft are significant in the airline industry. Other three other significant issues are; i) weather is variable and unpredictable. Extreme heat, cold, fog and snow can shut down airports and cancel flights, which costs an airline money, ii) fuel is an airline's second largest expense and it makes up a significant portion of an airline's total costs, although efficiency among different carriers can vary widely, iii) labor is the an airline's No.1 cost; airlines must pay pilots, flight attendants, baggage handlers, dispatchers, customer service and others [1].

People and businesses use air transport for many reasons. Individuals rely on it for holidays and visiting friends and family; while businesses use air transport for meeting clients and for the speedy and reliable delivery of mail and goods, often over great distances. One of the most important economic benefits generated by air transport is the intrinsic value generated for its consumers, passengers and shippers. With its speed, reliability and reach, there is no close alternative to air transport for many of its customers. This means that many are likely to value air services more highly than simply the price they are willing to pay for the ticket. But this added value will vary from flight to flight and from consumer to consumer, making it difficult to measure [2].

A measured rise in the number of travelers visiting friends and relatives reflects modern family demographics (with families spread over the world) and an increasingly globalized workforce. It further indicates stronger cross-border ties at both the individual and country level. This is particularly visible within the European Union, where the free movement of goods and people between its member states has developed social and economic networks that have long-lasting effects. It also brings benefits to both the host and originating countries in the form of increased social and economic integration. The free movement of goods and people has also helped provide the cohesion and links needed to develop a regional identity and ensure the continued development of the European Union. Labor mobility, which is a key contributor to long-term economic performance, is enhanced by air travel as it allows migrants to return home more often and allows friends and family to visit them in their new home. Also, once migrants return home, they have established new social (or family) networks in their country of stay, which will be more easily maintained via air travel. Diasporas can be an important source of trade, capital, technology, and knowledge for countries of origin and destination. According to the United Nations, more than 230 million people live outside their country of birth.

A key driver in the growth of passenger traffic has been the steady decrease in the real cost of air travel. Since 1970, the real cost of air travel has been reduced by over 60%, through deregulation of the aviation market in the 1980s, the development of more fuel-efficient aerospace technologies and the introduction of low cost carriers. It is now more affordable for more of the population to travel by air. In the United States, for example, the cost of a return flight from Boston to Los Angeles fell by 89% between 1941 and 2012, whilst the flight time is nine hours (and 11 stops) shorter [2].

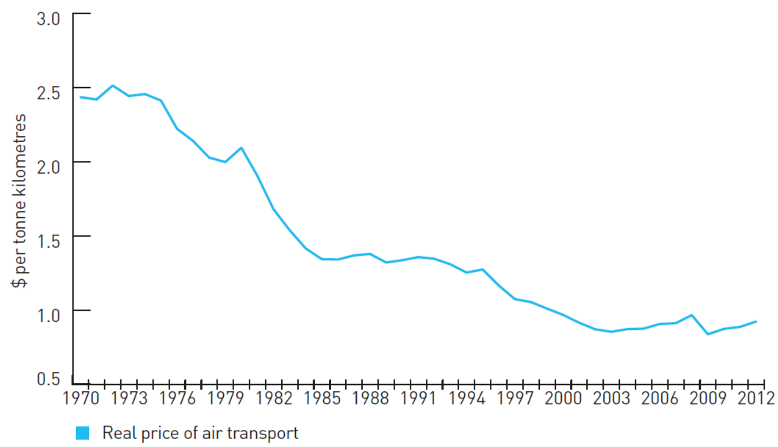

Figure 1. The real price of air transportation [2].

2. METHODOLOGY

The airline industry exists in an intensely competitive market and very thin profit margins make airlines highly cost sensitive and cautious. Although there are different categorization schemes for the airline industry, United States Department of Transportation Form 41 cost scheme has been widely used in the industry almost as a standard scheme for collecting, analyzing and reporting the costs. Form 41 contains traffic, financial and operating cost data [3]. It organizes data in administrative cost categories formatted in financial reports and functional cost categories which are used for airline cost and productivity comparisons. The Functional Cost Categories are separated as:

- **Aircraft operating costs** – Expenses associated with flying aircraft, also referred to as "Direct Operating Cost".
- **Aircraft servicing costs** – Handling aircraft on the ground, including the landing fees.
- **Traffic service cost** – Processing passengers, baggage and cargo at airport.
- **Passenger service cost** – Meals, flight attendants and in-flight services.
- **Promotions and sales cost** – Airline reservations and ticket offices, travel agency commissions.
- **Other costs** – Including general and administrative expenses, depreciation and amortization.

As based on historical "rules of thumb" values airline operating cost are grouped as:

- **Flight (Direct) Operating Costs (DOC) = 50%** – All costs related to aircraft flying operations including pilots, fuel, maintenance and ownership of the aircraft.
- **Ground Operating Costs = 30% –** Servicing of passengers and aircraft at airport stations including aircraft landing fees and reservations/sales charges.
- **System Operating Costs = 20%** – Marketing, administrative and general overhead items including in-flight services and ground equipment ownership.

In this study a specific segment of Regional Airline Operations are taken into account; initial stage of first time establishment of city to city commuter air transportation is accepted as a Public Welfare rather than a commercial entrepreneurship. Since it is accepted as a Public Welfare certain government incentives and subsidizations would be needed to lower the cost per customer to travel by aircraft in order to attract passengers from other means of transportation. It is viewed as two sided sacrifice and/or appreciation for the provided convenience by States and customer-passengers for this newly introduced way of transportation. In view of this objective costs are grouped in a way that cost reductions are considered in different means and levels.

2.1. Cost Items Re-organized for the Analysis

Costs items are grouped in this study as in three groups; a) airplane capital costs, b) cash airplane related operating costs and c) cash passenger related costs as shown in Table 1. All of these cost are calculated for different selected sector distances which are taken as 100nm, 200nm,…, 500nm. Most of these costs are function of the sector length and they are primarily calculated per flight and/or sector minutes or sector distances flown with an annual flight hour utilization of the considered aircraft. Based on the available open source data, an existing turboprop aircraft has been used to estimate the necessary input parameters for the detailed numerical analysis Ref [5, 6 and 7]. All calculations are based on the assumption that the considered aircraft is utilized 2,000 Flight Hours per year and average indirect course is around 15% of the total direct cost.

Costs are grouped as listed in Table 2 and descriptions and average actual values are provided. Ownership of aircraft is a major cost driver and the value of the considered aircraft ranges from 5 to 17 million US$ or in other words 70,000 to 150,000 US$ per month lease cost depending on the age of the aircraft. Cost of aircraft is considered with an average of 1% of the aircraft value per month and aircraft is assumed to be utilized as 2,000 flight hours per year. Based on the sector block hours cost of airplane is calculated for each sector considered. Similarly maintenance cost of aircraft is calculated for each sector as based on values per flight hours [5, 6 and 7].

Cost of cockpit and cabin crew is calculated as based on the assumption they are on duty for 600 flight hours per year. Crew salaries are considered at the level of world average and as based on the increasing demand for airline pilots in the world. As easily seen, cost of airplane can be varied at order of three times but maintenance and crew costs are accepted to be around nominal levels.

Table 1. Cost Items for the Considered Commuter Aircraft

Cost Item	**Unit in Calculations**	**Explanation**
Aircraft Financing	US$/sector	1% of aircraft value per month
Aircraft Insurance	US$/sector	1.8% of aircraft value per year
Crew (Cockpit + Cabin)	US$/sector	225,000 US$ per year, 600 Block Hours per year
Fuel	US$/sector	4.6 US$ per gallon
Maintenance	US$/sector	600 US$ per Flight Hour
A/C Ground Handling	US$/sector	15 US$ per available seat
Area Navigation	US$/sector	100 US$ Eurocontrol Unit Rate
Terminal Navigation	US$/sector	10 US$ per full 1,000 kg
Landing	US$/sector	18 US$ per full 1,000 kg
Passenger Handling	US$/sector	5 US$ per passenger per flight
Catering	US$/sector	Assumed to be served as paid

2.2. Sector Related Cost Data

Bringing different cost inputs dawn to sector level is found to be quite important. The considered 30-35 seat turboprop aircraft are known to have optimum sector range for high profitability between 200 to 350 nm but the commuter airline route network can have routes up to 500-600 nm and sector costs are calculated up to 500nm.

Table 2. Sector Related Cost Values

SECTOR RELATED DATA	Unit	Route 1	Route 2	….	Route 5
Sector Length	nm	100	200		500
Annual Utilization (Flight Hours) per A/C	FH/Year	2,000	2,000		2,000
Block Time per Sector	min	33	55		125
Block Fuel per Sector	kg	340	560		1,210

2.3. Surrogate Model for Lowest Possible Cost per Passenger

In this study a Operation Cost Surrogate Model is developed to as based on Design of Experiments and Response Surface Methods to analyze the different factors of operational cost of a commuter airline. As overall presented in Figure 2 cost analysis utilizes "airline traditional cost calculation tools" as explained in section 2.2. The independent input variables grouped as; revenue generating and cost items. Number of passengers carried defines the revenue generation and total cost of a selected sector is divided by number of passengers flown in that sector to find the break even ticket price for that given sector. A total of eight cost parameters are taken independent input variables in the analysis. Aircraft financing, the cost of aircraft ownership is calculated as based on value of the aircraft and total flight hours flown per year. Its value is taken as million US Dollars. Fuel cost is calculated as based on calculation of block fuel and multiplied by fuel price. Percentage of the fuel cost is taken as variable, where the 100% means no substitution is applied to fuel where as 40% means that 60% of the fuel is subsidized and only 40% of the fuel cost is reflected to the operation cost. Similarly; aircraft ground handling, area and terminal navigation (Air traffic Services provided) services and landing fees are considered as percentages of the actual costs which are reflected to the operational cost analysis. Costs of crew, maintenance and aircraft insurance are not taken as variable their actual calculated values are included in the analysis.

Output parameters of the operating cost analysis are costs for per passenger carried for revenue for five sectors; namely starting with 100nm to 500nm sector. Since aircraft flies to different routes the total operation cost is calculated with weight coefficients defined for each sector as given in Table 4, whereas the weight coefficient of the 100nm sector is taken as 5% representing that routes around 100nm constitutes only 5 % of all routes flown by that specific aircraft. Similarly the aircraft is assumed to be flying 35% on 300 nm routes.

A Microsoft Excel based program is developed for calculating the corresponding set of outcomes of the operation cost analysis for a given set of independent input parameters with a user friendly interface. An Overall Evaluation Criterion for cost (OEC_C), for the operation cost aspects of the commuter airline operations network which scores the overall balanced cost expectations calculated as illustrated in Figure 7. The OEC_C is defined as;

$$OEC_{Cost} = \frac{(\sum_i a_i \, Cost\ per\ Pax_i)_{BL}}{\sum_i a_i \, Cost\ per\ Pax_i} \tag{1}$$

A set of Design of Experiments (DOE) is constructed with the use of commercial JMP SAS software (JMP SAS 1994) and a Response Surface is obtained for the defined OEC_C. This Response Surface is the Surrogate Model of the Operation Cost analysis (EIF-SM) and it is a surface function of the selected independent input variables.

Table 3. Design of experiments considered values

Input Variable	**Unit**	**Minimum**	**Maximum**
Number of Average Passengers		20	30
Aircraft Market Price	Million US$	5	12
Fuel Cost	% of the actual cost	40	100
Aircraft Handling	% of the actual cost	20	100
Area Navigation	% of the actual cost	20	100
Terminal Navigation	% of the actual cost	20	100
Landing Fees	% of the actual cost	20	100
Indirect Costs	% of the Total Direct Operational Cost	5	20

Table 4. Weighting of sectors in the network

100nm	200nm	300nm	400nm	500nm
a_1	a_2	a_3	a_4	a_5
5%	25%	25%	35%	10%

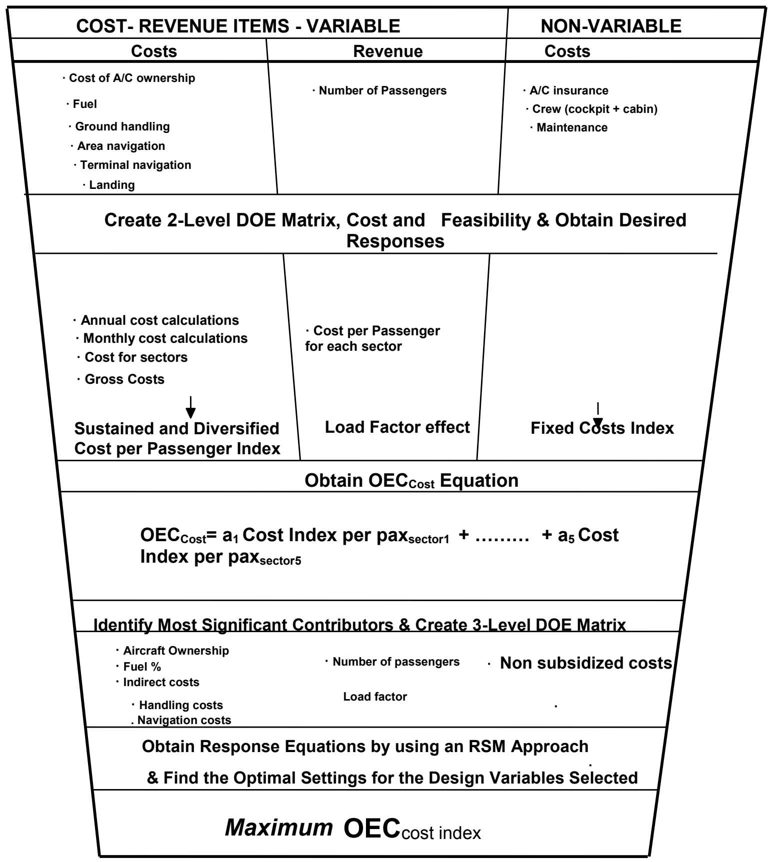

Figure 2. Design of Experiments and Response Surface decision Funnel for Commuter Airline Network Costs.

3. RESULTS AND DISCUSSION

Results are obtained for a network consisted of routes between 100nm to 500nm with weighting coefficients given in Table 4. Since the main objective of the analysis is to observe effect of different cost items on a defined one overall non-dimensional OEC_{Cost} parameter. Costs per passenger for each sector are divided by reference costs per passenger for each route sector which are also given in Table 5. A set of Design of Experiments (DOE) is constructed with the use of commercial JMP SAS software [8] with 2 sets of combinations of maximum and minimum values of the considered input variables which are also listed in Table 3. The corresponding Response Surface is obtained for the defined OEC_{Cost}. This Response Surface is also the Surrogate Model of the Operation Cost analysis (OC-SM) and it is a surface function of the selected independent cost input variables.

Table 5. Baseline cost per passenger for sectors.

	100nm	200nm	300nm	400nm	500nm
US$/pax	50	60	70	80	90

One important output of the DoE analysis is the Pareto Chart which ranks input variables in terms of their effects on the defined $OEC_{Cost.}$ The Pareto chart obtained for the example analysis indicates that *number of passengers* is the most important input variable which is followed by fuel cost subsidization percentage and aircraft value as the second and third input variables successively, as shown in Figure 3. The indirect cost which is defined as the percentage of the total direct cost comes as the fourth important variable.

Response Surface obtained for the Operation Cost Analysis which is constructed as based on the conducted Design of Experiments analysis. Figure 4 shows the user interface for the response surface of the defined non-dimensional OEC_{Cost} as function of eight independent input variables. A value of 0.532 is obtained for OEC_{Cost} for mean values of input variables. The user friendly interface helps us to calculate new corresponding values of OEC_{Cost} for each set of selected input variable values. Figure 5 shows a set of input variables which gives a possible low value for OEC_{Cost} and Figure 6 represents a set of input variables which gives a high value for OEC_{Cost}.

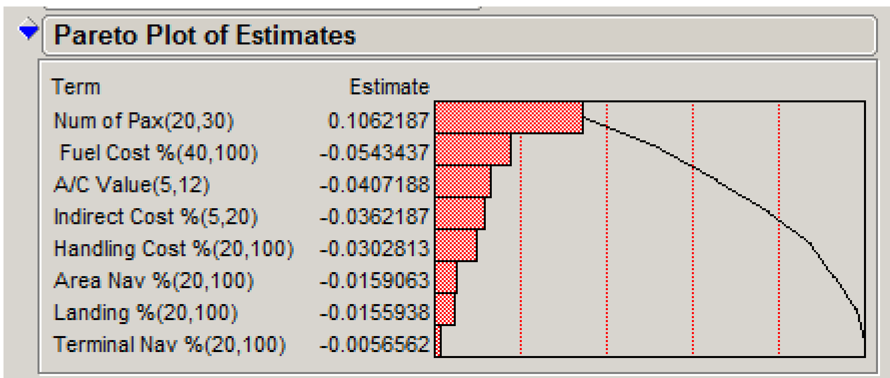

Figure 3. Design of Experiments Pareto Chart Result for the Commuter Airline Network Cost Analysis.

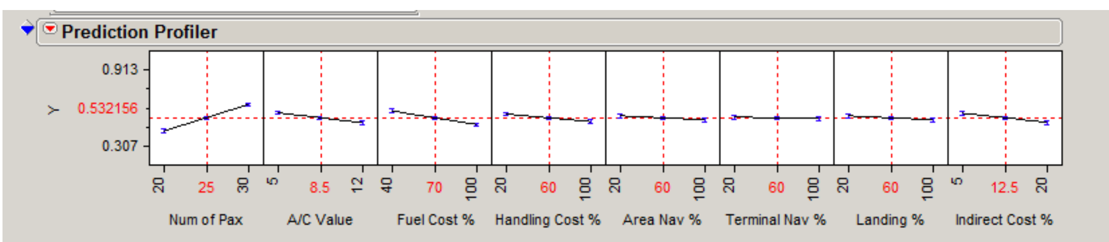

Figure 4. Sample Response Surface user interface for Commuter Airline Network Cost Design of Experiments Analysis; for the mean values of the input variables.

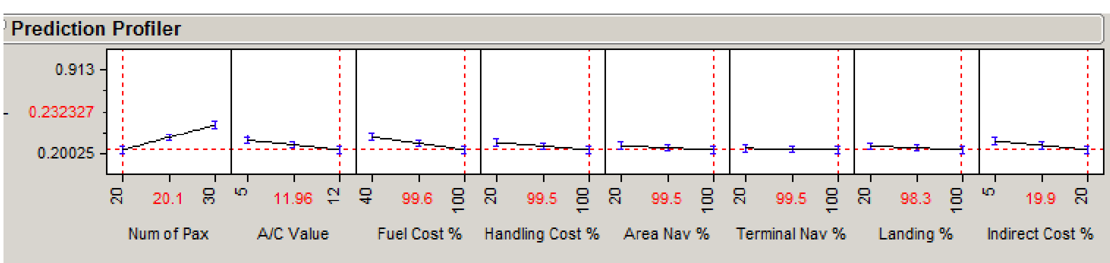

Figure 5. Sample Response Surface user interface for Commuter Airline Network Cost Design of Experiments Analysis; for the set values of the input variables which gives the least desirable OEC_{Cost}.

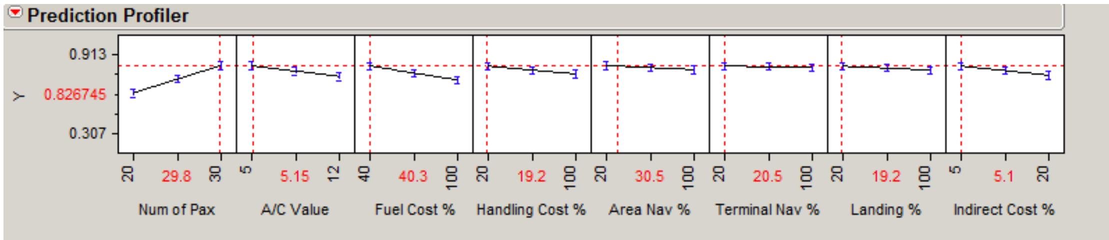

Figure 6. Sample Response Surface user interface for Commuter Airline Network Cost Design of Experiments Analysis for the set values of the input variables which gives the best desirable OEC_{Cost}.

4. CONCLUSION

The developed Operation Cost and Feasibility analysis tool for operational cost analysis for city to city commuter airline network operations is found to be a useful tool for modeling cost and operation feasibility aspects. It helps us first in breaking down cost inputs in a way that one can identify costs which can be reduced and/or subsidized by relevant government authorities. Secondly the developed Surrogate Model for the Operation Cost and Feasibility analysis helps us to calculate a new OEC_{Cost} value in seconds which helps capturing different cost input alternative combinations.

Based on these valuable sides, the newly introduced Surrogate Model can be further be developed as;

- OEC_{Cost} can be calculated for sets of alternative network of actual routes considered to be operated,
- More realistic maximum and minimum values for different cost items can be defined,
- The cost and feasibility analysis model can be expanded for different aircraft types and networks of commuter airline operation models.

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